CALORIMETRIC INVESTIGATION OF GAS ENTERING THE NOZZLE OF A LOW-DENSITY HIGH-VELOCITY WIND TUNNEL

BY

RONALD GEORGE BARTH
B. S., United States Military Academy, 1963

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Aeronautical and
Astronautical Engineering
in the Graduate College of the
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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY RONALD GEORGE BARTH

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BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AERONAUTICAL AND ASTRONAUTICAL ENGINEERING

H S Stillwell
In Charge of Thesis

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Recommendation concurred in†

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† Required for doctor's degree but not for master's.

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I would like to acknowledge the helpful and timely advice given me by Professor H. S. Stillwell, Head of the Aeronautical and Astronautical Engineering Department. I would also like to thank the men of the Department's shop, the women of the Department's office, and my wife whose efforts made this work possible.

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NOTATION

A	area
a	speed of sound
C_p	specific heat at constant pressure
^oF	degrees Fahrenheit
g_c	$32.17 \frac{lb_m\ ft}{lb_f\ sec^2}$
H	enthalpy
K	constant
k	specific heat ratio
M	Mach number
P	pressure
PC	power control setting
R	gas constant
^oR	degrees Rankine
T	temperature
V	velocity
w	mass flow rate
ϱ	density

Subscripts

g	gas property
c.w.	cooling water property
*	sonic throat condition
o	stagnation condition
E	conditions at calorimeter exit
S	stilling chamber condition

1. INTRODUCTION

The impetus for conducting a calorimetric investigation of an arc-heater generated flow entering the diverging section of a supersonic nozzle was initiated by construction, at the University of Illinois, of a low-density, hypervelocity wind tunnel. This wind tunnel, which was built under the auspices of the Departments of Aeronautical and Astronautical Engineering and Mechanical Engineering, consisted of an arc-heater, stilling chamber, supersonic nozzle, test chamber, adjustable diffuser, and a steam-ejector vacuum pump.

A confined-arc plasma generator was selected for the heater to raise the working gas to the high temperatures required for performance in the hypervelocity, as opposed to the hypersonic, range. The high gas temperature was also desirable in order to achieve a substantial temperature difference between the working gas and the model wall. The resulting temperature gradient in the boundary layer surrounding the model would allow for a better simulation of viscous interactions and therefore, would yield better aerodynamic test results.

Since all of the major components of this tunnel were of recent design and/or manufacture, the decision was made to test separately each of the elements before attempting to activate the entire system. In particular, a bench test of the arc-heater and the stilling chamber was proposed. Individual component testing of the six-stage, steam-ejector system had not been done so a newly installed vacuum pump and

tank farm system were utilized for the heater tests. Although the final wind tunnel vacuum system will be capable of producing very low pressures, the 27 inches of mercury vacuum available from the tank farm was more than sufficient for the current tests since only a pressure ratio across the nozzle throat sufficient to produce sonic flow was required.

The purpose of this bench test was two-fold. First, it was desired to establish the reservoir conditions (that is, stagnation conditions in the stilling chamber) from which other flow characteristics could be determined. Second, it was desired to determine whether the chosen stilling chamber length was sufficient to allow the plasma to recombine and relax into an equilibrium state.

Four additional results could be anticipated from the series of tests. First, by means of an energy balance, it would be possible to calculate the arc-heater efficiency. Second, since several sections of each component of the test apparatus were cooled separately, it would be possible to establish the heat losses per section. Third, the use of a water cooled stagnation pressure probe could be compared to a static tap located in the converging section of the nozzle for use in obtaining suitable pressure readings. Four, the bench test would give the departments an opportunity to check out the equipment, establish operating procedures, and train personnel.

Since successful use of the equilibrium sonic flow method would realize these purposes, it was necessary only to establish the appropriate testing conditions and procedures.

Two possible methods of providing an experimental check on the total enthalpy calculated by the sonic flow method were considered. One method, that of a total energy balance ---subtracting cooling line heat losses from the electrical power input---was disregarded since the overall efficiency of the apparatus was anticipated to be less than 20 percent. In this range of efficiencies a small error in one of the cooling line measurements would cause a much greater error in the resulting total enthalpy calculation. The second method considered---and the one chosen for this experiment---was that of total calorimetry. Specifically, a total calorimeter was designed and built to establish by direct measurement the stagnation enthalpy at the nozzle throat.

2. THEORY

The theoretical basis upon which the experimental data were evaluated was the equilibrium sonic flow method. This method could be used with any gas and with any known thermochemical state of that gas.[11] In this experiment, the assumptions were made the gas was in an equilibrium state (thermal and chemical) and that it flowed isentropically from the reservoir to the sonic throat. With these assumptions, the readily measureable quantities of mass flow rate, stagnation pressure, and sonic throat area were used to determine the stagnation enthalpy at the throat.

The procedure followed is summarized below. First, a curve of H_o versus w/P_oA^* had to be established. This was

accomplished by assuming various values of T^* within a range where the enthalpy was essentially independent of the pressure. Since the speed of sound, a^*, associated with T^* could also be calculated for a perfect gas, the stagnation enthalpy was determined for each T^* by

$$H_o = H^* + 1/2\, a^{*2} \text{ with } H^* = H^* (T^*) \text{ and } a^* = \sqrt{kRT^*}$$

In order to relate w/P_oA^* to T^*, and thereby to H_o, the continuity equation was used to give

$$w = \rho AV = \frac{P}{RT} AV = \frac{PA\sqrt{kg_c}}{\sqrt{RT}} \frac{V}{\sqrt{kRTg_c}} = PAM\sqrt{\frac{kg_c}{RT}}$$

which was true for a perfect gas.

For isentropic flow of a perfect gas, substitution of P_o for P yielded

$$w = P_oAM\sqrt{\frac{kg_c}{RT}} \left[1 + \frac{k-1}{2} M^2\right]^{-\left(\frac{k}{k-1}\right)} .$$

For sonic conditions, i.e. M = 1, rearranging gave

$$\frac{w}{A^*P_o} = \left[\sqrt{\frac{kg_c}{R}} \left(\frac{2}{k-1}\right)^{\frac{k}{k-1}}\right] \frac{1}{\sqrt{T^*}} .$$

If k was constant in the range of T^*'s considered, then

$$\frac{w}{A^*P_o} = K \frac{1}{\sqrt{T^*}}$$

where K = K (k, R) = constant.

Therefore, with the restrictions mentioned above, assuming a value for T^* yielded a relationship between H_o and

w/P_oA^*. A plot of this relationship is given for argon on Figure 5 and for nitrogen on Figure 6.

As stated above, an integral part of the equilibrium sonic flow method was the determination of the sonic throat area, A^*. It was demonstrated in Reference 2 that assuming the sonic throat area to be the throat area of the nozzle would result in less than a .3 percent error. The argument stated that considering only the viscous boundary layer the sonic point would be downstream of the throat, while considering only the heat losses the sonic point would be upstream of the minimum area. These two effects tended to counteract each other to the degree that the accuracy of the other measurements attained.

3. EXPERIMENTAL APPARATUS AND PROCEDURE

3.1. Apparatus

The experimental set-up is shown on Figure 1. The principle components of the apparatus were the arc-heater, the stilling chamber, the nozzle, and the total calorimeter. In addition to these major components there were the power supply, control console, vacuum system, cooling system, millivolt potentiometer and thermocouples. A discussion of each of the major components and the more important instrumentation follows.

The arc-heater, with minor modifications, was Plasmadyne's plasma generator model SG-102. Modifications included an anode extension to contain the arc and a means of

adding an additional gas to the plasma as it left the anode. The heater power supply had three possible open circuit voltages (OCV). Each voltage setting had an associated current capacity e.g., 80 OCV, 1000 amps.; 160 OCV, 500 amps.; and 320 OCV, 250 amps. It was possible to sustain overloads for 3 to 4 minutes without damaging equipment.

The operator's control console, shown on Figure 2, monitored DC voltage, current, and gas and cooling water flows to the arc-heater. Safety devices prevented operation of the heater without sufficient mass flows of water and gas.

The stilling chamber was designed by Professor J. L. Loth of the Aeronautical and Astronautical Engineering Department of the University of Illinois. It was a 3 inch inside diameter, water cooled, cylinder with a port at its downstream end to receive a pressure probe. A length of 5 1/2 inches was chosen in order to allow the arc-generated plasma to relax to a thermo-chemical equilibrium state before entering the nozzle. The converging section of the nozzle, also designed by Professor Loth, had an area ratio of 4×10^4, which yielded a minimum constriction of .150 inches in diameter. This section included a static pressure tap and was cooled by a separate water jacket. Both of these sections were made of cooper inserts silver soldered to brass casings and flanges.

The total calorimeter, designed by the author, was needed to reduce the gas temperature to a readily and accurately measureable level. The calorimeter consisted of a diverging nozzle, a heat exchanger, and a stagnation pressure probe. The diverging nozzle had an inlet area larger than the

throat of the stilling chamber converging nozzle so as to allow the calorimeter to be used at sections further downstream from the throat in future experiments. The heat exchanger consisted of five 3/8 inch outside diameter copper tubes which were each 14 inches long. These tubes were nested in baffles which gave the cooling water a positive path to follow through the exchanger. The stagnation pressure probe was permanently mounted along the axis of the heat exchanger and was used to monitor pressures at the nozzle exit. The entire calorimeter was designed in such a way that replacement or substitution of its various components could readily be accomplished. An assembly drawing appears on Figure 3 and a photograph on Figure 4.

Three pressure readings were desired: the stilling chamber stagnation and static pressures and the nozzle exit stagnation pressure. The latter, described above, was used to determine when sonic conditions had been reached at the throat. The static readings in the stilling chamber were accomplished by locating a hole perpendicular to the nozzle wall. However, stagnation pressure readings in the stilling chamber had to be obtained with a water-cooled pressure probe. Due to the extremely small throat area, ablation or destruction of a probe in the stilling chamber could have proved disasterous. The final design was a machined and bored, brass rod fitted inside a 3/8 inch copper tube, which served as a water jacket. Provision was made to permit removal of the probe from the chamber so that its effect on the flow could be determined.

All three pressure readings were made on standard mercury manometers.

Copper-constantan thermocouples were used to measure all cooling water and gas temperatures. The water line thermocouples were held by apoxy-resin in the center of 3/8 inch brass rods, which had two holes drilled along their axes to accept the wires. Each brass rod was then located in one side of a tee placed in every cooling line. The thermocouple at the exit from the calorimeter, which measured exiting gas temperature, was inserted in a ceramic rod made for this purpose. The thermocouples were individually calibrated and each required a correction of - .0025 millivolts. All readings were made on a millivolt potentiometer used in conjunction with a switch box and a reference junction of 32° F. The potentiometer had an accuracy of $\pm$ .0025 millivolts.

3.2. Procedure

A series of tests was designed to establish operating ranges of individual components of the experimental apparatus. This involved determining the best starting procedure for the arc-heater and checking the effectiveness of the cooling system of each component throughout the entire range of operation of the arc-heater. Specifically, tests were completed with the arc-heater operating alone and open to the atmosphere; with the stilling chamber and nozzle attached to the heater, but still open to the atmosphere; and finally, with all of the components, including the calorimeter, operating with the controlled vacuum supplied by the vacuum system. During each

of these tests, attempts were made to establish ranges of operating conditions by varying the mass flow rates of the working gases, the voltage, and the current in different combinations. Data obtained from these tests would then serve to define the specific testing procedure required to determine the stagnation conditions throughout the entire operating range of the arc-heater.

In order to simplify the evaluation of the equipment and procedures, the current series of tests was begun with argon. Since argon was inert and monatomic, ionization was the only non-equilibrium problem encountered at the higher temperatures and it behaved as an ideal gas in the range of temperatures at the throat. After some experience had been gained with argon, an attempt was made to switch to nitrogen.

In order to protect the electrodes and give them longer life, all of the tests were begun with high, gas mass flows and low power supplied to the arc-heater. In particular, argon was introduced around the cold torch at a predetermined mass flow rate once sufficient cooling water was circulating throughout the apparatus. The torch voltage and stilling chamber pressure were then adjusted to desired values and the arc was initiated. The procedure was then to lower the mass flow rate and increase the electrical power while observing and recording the behavior of the instruments and apparatus for each set of input conditions. As the mass flow of argon was reduced, nitrogen flow was started and a gradual transition was made until the change to nitrogen had been completed.

In this way a partial operating range for each working gas was established.

4. RESULTS

The calorimetric investigation was severaly limited by cooling water leakage from jackets around the arc-heater anode extension, the stilling chamber, and the converging nozzle. These components were fabricated from brass and copper using silver soldered joints which developed leaks when subjected to the severe temperature changes encountered. It was determined that a complete redesign of these components was necessary, and although the experiments provided essential data for the design of the parts required for installation in the wind tunnel, the time required to build new parts was too great to make them available for this series of tests. Nevertheless, the tests were successful in establishing operating procedures and in determining ranges of operation.

4.1. Equipment Performance

A discussion of the performance of the arc-heater, stilling chamber, nozzle, and calorimeter follows. In addition, the more important auxiliary equipment and instrumentation is evaluated.

A test of the arc-heater without the anode extension resulted in the foot of the arc attaching itself to the outside of the mounting and cooling flange surrounding the anode exit. However, with the addition of the extension, the arc-heater functioned properly. While the anode extension served

its purpose of containing the arc, it did not remain properly seated on the arc-heater. As a result, water leakage from its cooling jacket flooded the stilling chamber. Although no water could exist within the arc-chamber because of the high temperature, a final check of the arc-heater and extension, operated by themselves, resulted in an unstable arc.

The stilling chamber dimensions appeared to be satisfactory for providing mixing and equilibrium of the plasma stream. However, after several minutes of operation, a cooling water leak occurred at the downstream flange causing water to back up from the 'O' -ring seal in this flange which flooded the bottom of the stilling chamber. A small, and apparently intermittent leak, was also discovered at the port provided for the stagnation probe.

Two primary design objectives of the sonic nozzle were successfully realized. The nozzle throat reached sonic conditions as indicated by the pressure readings, and the plasma stream striking the converging nozzle did not damage the interior walls or the minimum-area section. Performance, however, was restricted by the fact that all of its joints leaked cooling water at some time during the testing. Some of this water was blown downstream and was observed flowing out of the throat, and the remaining water ran back into the stilling chamber.

The calorimeter operated without any apparent gas or water leakage. At one stage of the experiment, the entire calorimeter was dismantled, inspected, and reassembled. During this inspection it was noted that all the seals were

functioning properly. Nevertheless, due to the limitations on operations imposed by the other major components, the complete performance of the calorimeter could not be determined. Based on tests that were conducted, the cooling water temperature increased according to predictions but the exit gas temperature was considerably higher than predicted. However, this temperature was in the range suitable for measurement with the thermocouple used, and the calorimeter should be satisfactory for future experiments.

The auxiliary equipment---water and vacuum pumps and systems---was acceptable. A water pump leak occurred around the shaft connecting the motor and pump, but this condition was accepted to avoid a time-consuming complete overhaul. Pressure in the cooling lines was marginal but could be maintained at the required level as long as there was no pressure drop in the supply from the mains. The vacuum system performance was flawless although it was being used for the first time. The pump reduced the pressure in the tank farm to approximately 1.75 inches mercury in less than ten minutes, and with the pump turned off the storage capacity was large enough to run the heater for extended periods with only 1/2 inch mercury pressure rise.

The arc-heater console was easily monitored, and the safety devices built into it were effective. Control of the arc-heater and gas flow was readily obtained except during changeover from argon to nitrogen. While this operation was being performed, two out of three times some difficulty was

encountered. As expected, operation with argon was more easily controlled than with nitrogen.

The instrumentation for this experiment was satisfactory, and all pressures, temperatures, and mass flow rates were obtained within the desired accuracy.

Accurate pressure readings were obtained with a 90 inch U-tube and a 60 inch single tube mercury manometer. Vacuum-pressure gauges were installed in the lines leading to the manometers, and were separated from the manometers by valves so that steady operation of the heater could be obtained before opening the lines to the manometers. This prevented surges of the mercury columns. A water leak occurred around the static pressure tap in the nozzle suggesting the need for improved design when this part is built for the final wind tunnel installation.

The thermocouple fittings designed to seal against water and gas leaks were satisfactory, but very small leakage occurred between the leads and their insulation. This can be corrected readily by sealing the insulation as it emerges from the fittings.

Gas mass flow meters provided on the control console furnished by Plasmadyne functioned properly although some flutter of the indicator occurred during starting with the chamber at approximately 2 inches mercury pressure. This disappeared as soon as the flow rate was increased beyond a flow meter reading of .5. The correction factor charts shown on Figures 7, 8, and 9 can be used to correct the meter readings for gas density and pressure. Meter readings of

.5 to 1.0 would yield argon mass flow rates in the order of 10 lbm/hr while readings of 1.0 to 1.5 would yield the same flow rates for nitrogen.

4.2. Procedure

A starting procedure was devised and is outlined in the Appendix. This procedure covered all actions to be accomplished from starting the vacuum pump to the final arc 'on' condition.

Each of the tests conducted during the final five-day period was run by two or three persons. During each run one person operated and monitored the control console while a second person operated the potentiometer and adjusted the cooling water flow rates from the manifold to obtain desired temperatures. A third person measured mass flow rates of the cooling water.

In general, starting at a high mass flow and low power setting proved most desirable. All starts were made with argon, but after steady-state conditions were reached, attempts were made to phase in nitrogen while phasing out argon. The best procedure for switching from one gas to the other with the arc in operation was not perfected since some difficulty was encountered at each changeover. The trend was for the voltage to increase and go out of control. This condition occurred as the ratio of argon to nitrogen was reduced and the power control setting increased to prevent the current from dropping off to zero.

The experimental data were reduced by correcting the flow meter readings for gas pressure and temperature. The flow was then divided by the stilling chamber pressure and an experimental point was obtained which could be located on the curve of w/P_o versus H_o at the enthalpy level obtained from the calorimeter. An experimental value of enthalpy was

$$H_o = \frac{\left[w\ C_p\ (T_{out} - T_{in}) \right]_{c.w.}}{w_g} + \left[C_p\ T_{exit} \right]_g$$

The cooling water leaks prevented obtaining useful experimental results.

The performance ranges indicated by the series of tests are shown in Table I. Table II shows the temperatures recorded during Test 3 and Tables III and IV are sample results from Test 5.

TABLE I. TEST SCHEDULE

Test 1

Gas	Mass Flow	at Pressure	PC	Amps	Volts	KVA
* A	1.8	22	20	350	32	11.2
A	1.8	22	32	500	36	18.0
A	1.6	22	42	600	40	24.0
A	1.0	10	42	600	40	24.0
A	1.0	10	62	750	42	31.5
A	1.5	17	62	750	42	31.5
		Test 2				
* A	1.8	20	20	350	22	11.2
A	1.5	19	68	850	44	37.4
* A	1.4	14	20	350	30	10.5
A	1.4	15	40	600	36	21.6
A	1.4	15	54	700	40	28.0
		Test 3				
* A	2.0	22	20	350	32	11.2
N_2	1.2	15	60	400	86	34.4
N_2	1.2	15	60	425	82	34.8
N_2	1.5	26	63-77	400-460	92	43.3
* A	1.5	12	20	350	32	11.2
+ N_2	1.4	23	69	450	88	39.6
+ N_2	1.3	18	61	400	88	35.2

*starting conditions

+temperature readings (see Table II)

TABLE I. TEST SCHEDULE (continued)

Test 4

Gas	Mass Flow	at Pressure	PC	Amps	Volts	KVA
Open Circuit Voltage = 80v						
* A	2.0	23	20	150	35	5.25
A	1.9	25	34	500	31	15.0
A	1.9	28	43	600	34	20.4
A	1.9	29	52	700	38	26.6
A	1.9	29	56	750	39	28.5
A	1.9	33	65	860	40	34.4
Open Circuit Voltage = 160v						
* A	2.0	23	20	325	32	10.4
A	1.9	25	29	475	32	15.2
A	1.5	18	29	475	32	15.2
Open Circuit Voltage = 320v						
* A	2.0	22	20	200	40	8.0
A	1.9	24	30	300	32	9.6
A	1.9	24	26	275	32	8.8
A	1.9	24	18	200	32	6.4
A	2.1	30	18	200	32	6.4

*starting conditions

TABLE I. TEST SCHEDULE (continued)

Test 5

Gas	Mass Flow	at Pressure	PC	Amps	Volts	KVA
* A	1.5	8	30	425	40	17.0
+ A	1.4	12	28	425	40	17.0
A & N_2	.9 & .5	--	30	200	60	12.0
* A	1.5	12	30	450	40	18.0
A & N_2	.8 & 1.2	--	54	350	88	30.8

*starting conditions

+temperature readings (see Tables III and IV)

TABLE II. TEMPERATURE RECORDINGS*

Manifold	Flange	Stilling Chamber	Nozzle
.58 (59^o)	.77 (69^o)	.966 (76^o)	.83 (70^o)
.58 (59^o)	.995 (77^o)	1.45 (97^o)	1.31 (91^o)
.58 (59^o)	1.00 (77^o)	1.335 (92^o)	1.26 (89^o)
.58 (59^o)	1.05 (80^o)	1.78 (111^o)+	1.28 (90^o)

*readings in millivolt and degrees Fahrenheit

+water flow rate changed in the stilling chamber

TABLE III. RAW DATA FROM SAMPLE TEST RUN

Gas:	Argon (bottle bleed at 50 psi)	
Gas Mass Flow Rate:	1.4 at 12 psi	
Power Control Setting:	30	
Power:	425 amps at 40 volts (17. KVA)	
Pressure:	P_{o_E}	= - 16.2 inches mercury
	P_S	= - 7.13 inches mercury
Temperature:	Manifold	= .575 millivolts
	Calorimeter	= .630 millivolts
	Gas Exit	= 1.894 millivolts
	Nozzle	= .630 millivolts
	Stilling Chamber	= .785 millivolts
	Flange	= .765 millivolts
Cooling Water Flow Rate:	5 lb./16 sec.	

TABLE IV. REDUCED DATA FROM SAMPLE TEST RUN

Gas:	Argon (bottle bleed at 50 psi)	
Gas Mass Flow:	13.08 lb_m/hr	
Power Control Setting:	30	
Power:	425 amps, 80 volts, 17. KVA	
Pressure:	P_{o_E} = 7.96 psi vacuum	
	P_S = 3.5 psi vacuum	
Temperature:	Manifold	= 59° F
	Calorimeter	= 61° F
	Gas Exit	= 116° F
	Nozzle	= 61° F
	Stilling Chamber	= 68° F
	Flange	= 67° F
Cooling Water Flow Rate:	.312 lb./sec.	

5. CONCLUSIONS

Due to cooling water leaks which could not be eliminated in a reasonable time, the primary objective of this experiment could not be fully realized. The investigation did, however, point the way to proper redesign of the anode extension, stilling chamber, and converging nozzle for the final wind tunnel installation. The aerodynamic considerations that went into the original design of these components were satisfactory. Therefore, attention in the new design should be directed toward reducing the number of parts in each assembly and making the parts replaceable by using insertable seals. The dimensions of all components appear to be satisfactory.

Since no problems were encountered with the arc-heater or calorimeter, continued use of these components in their present condition is recommended.

Recommendations for modifying associated equipment may be confined to the water system since all other apparatus performed within predicted limits. Since pump performance was marginal, i.e., it increased the pressure to only 85 psi, replacement of the pump with a larger model is recommended.

Instrumentation performance was acceptable but two minor refinements are suggested. First, the thermocouple wires, where they enter the insulation, should be sealed with apoxy-resin. Second, U-tube manometers should be used for all three pressure measurements.

The starting procedure devised should be followed precisely. However, further experimentation with the

changeover procedure from argon to nitrogen is needed to perfect a method which will assure controllability during this process. Furthermore, during the experiments only maximum power was obtained during runs using nitrogen and additional experience with the arc-heater is needed to perfect operation over the full power range.

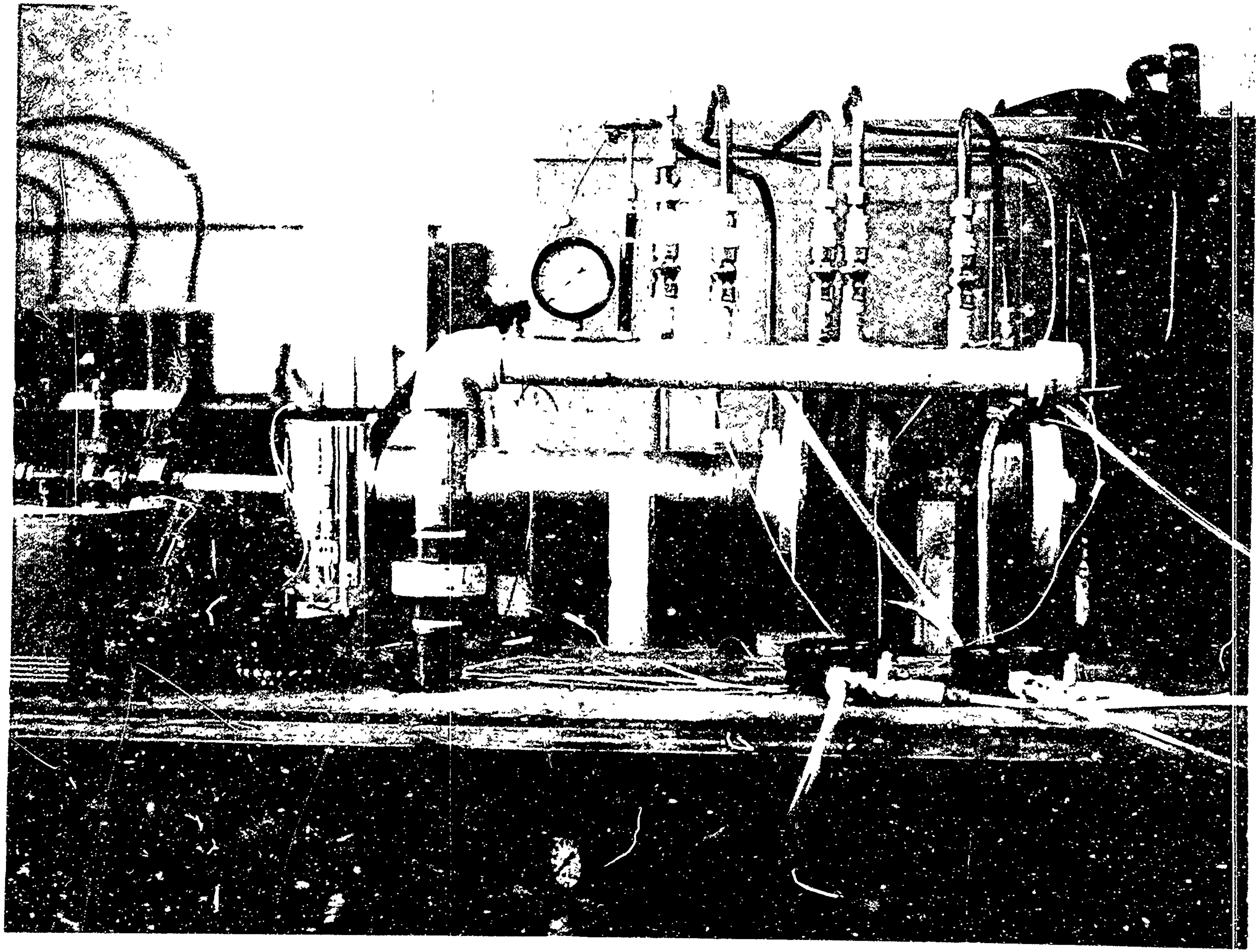

Figure 1. General Assembly of Apparatus

Figure 2. Control Console of Arc-Heater

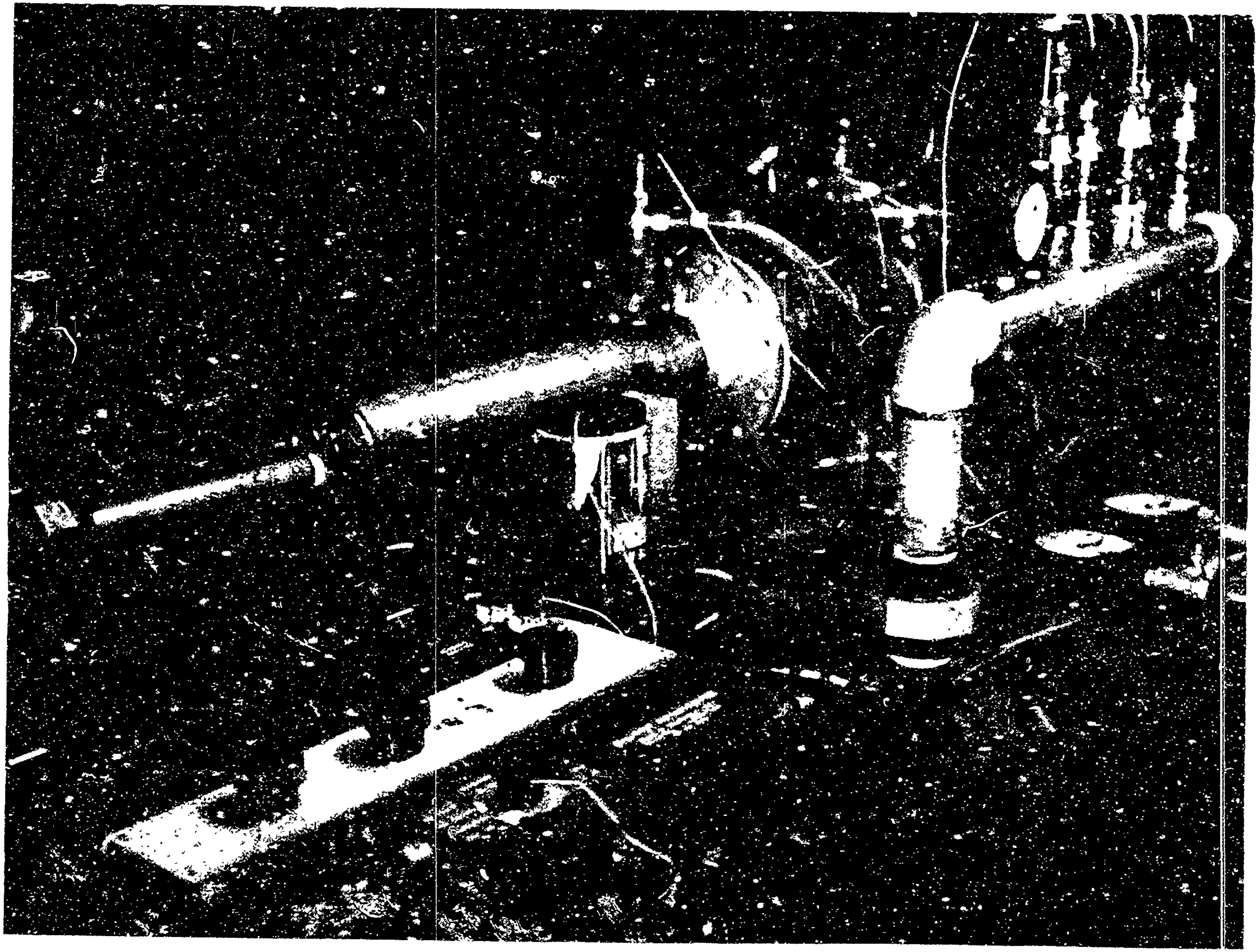

Figure 4. Assembled Apparatus Showing Total Calorimeter From Gas Exit End

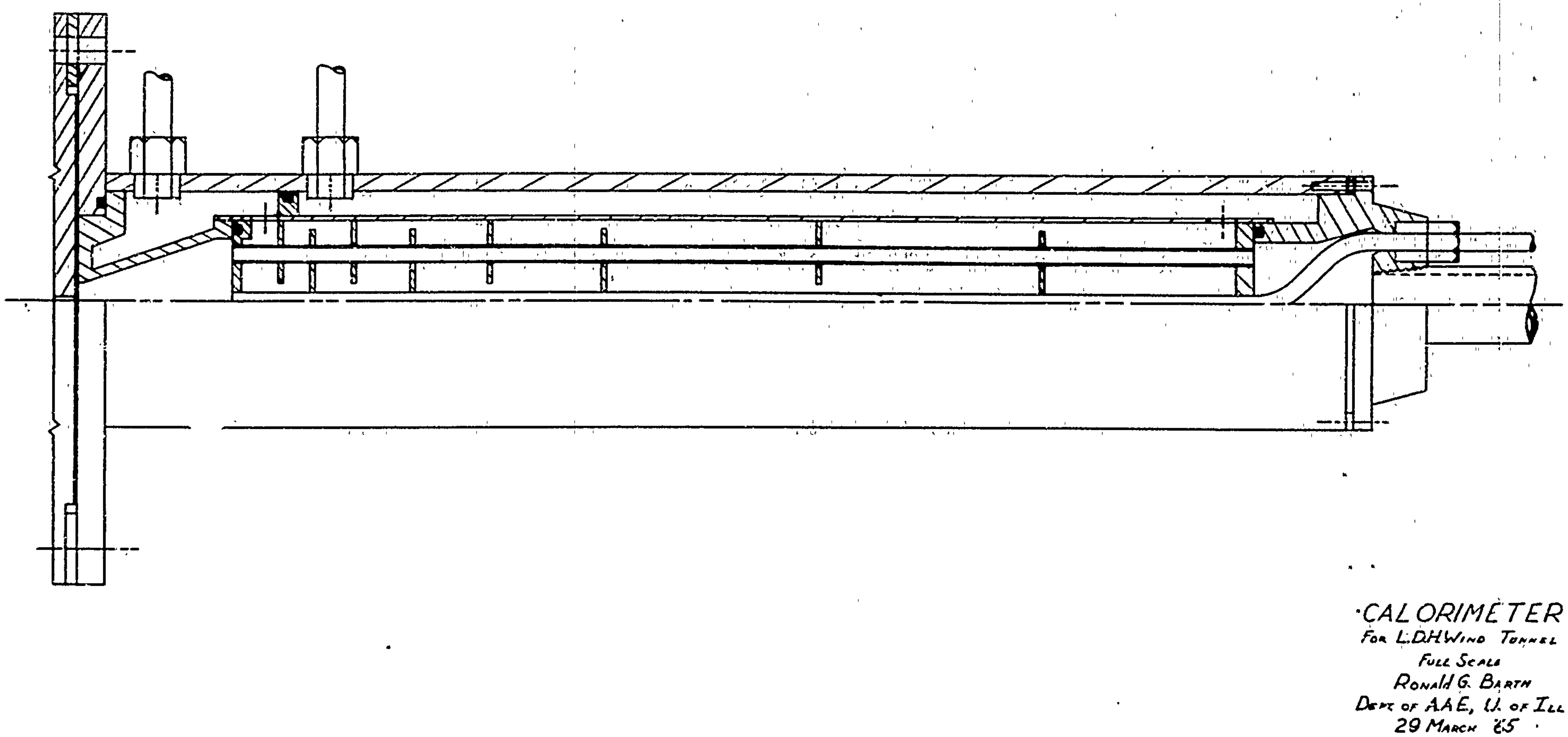

Figure 3. Calorimeter Assembly Drawing

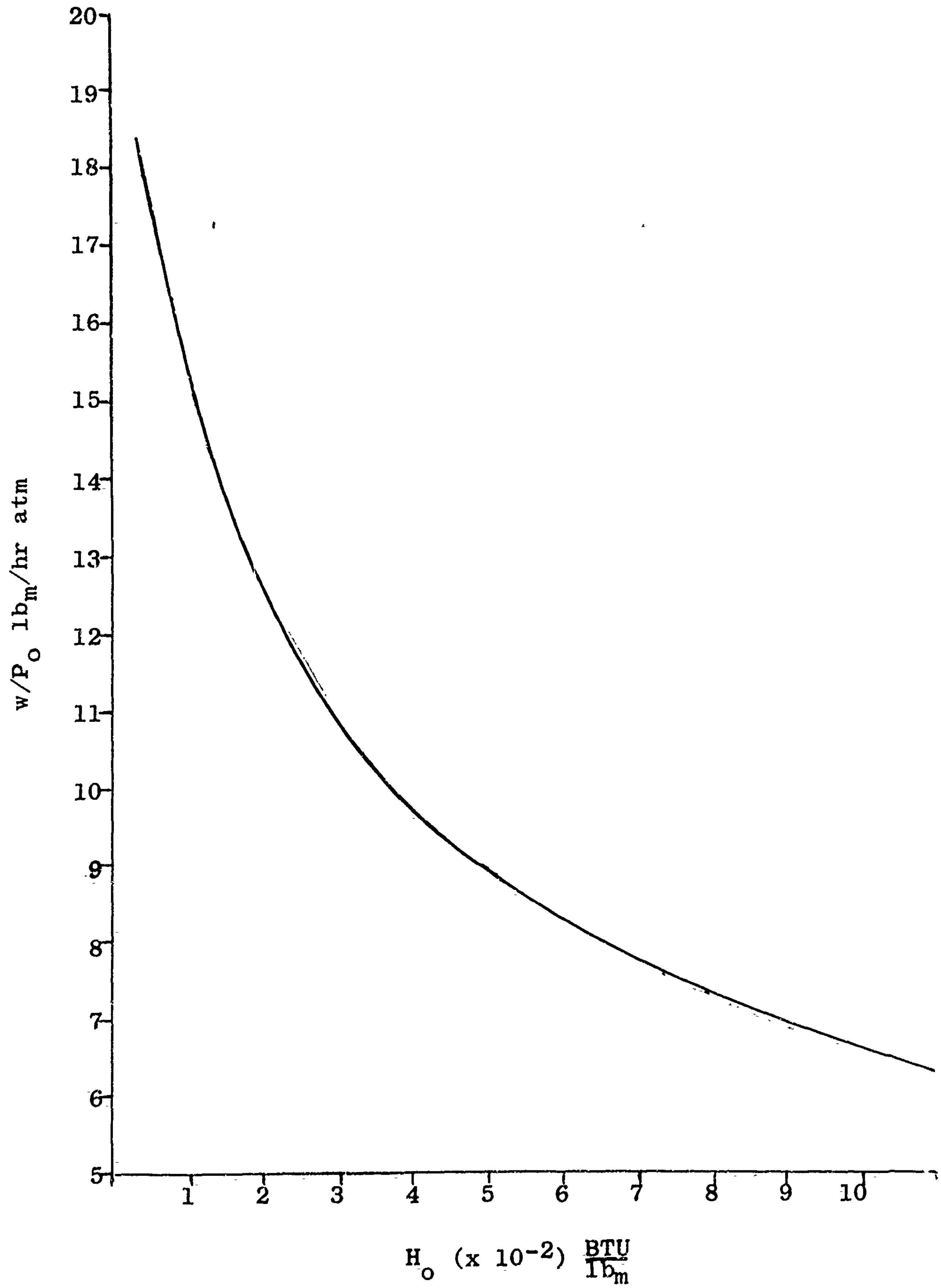

Figure 5. Enthalpy versus $\frac{\text{Mass Flow Rate}}{\text{Stagnation Pressure}}$ for Argon

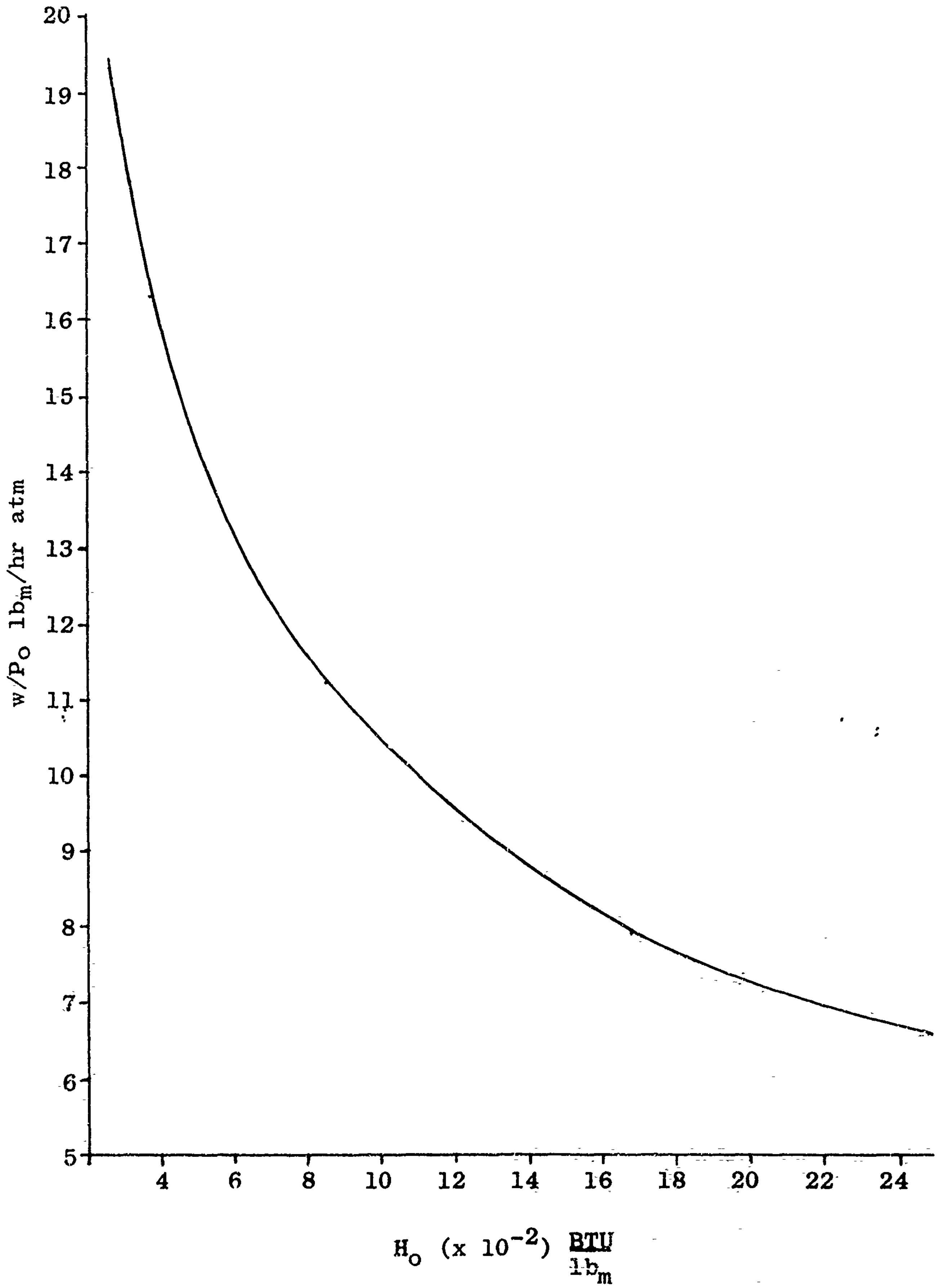

Figure 6. Enthalpy versus $\frac{\text{Mass Flow Rate}}{\text{Stagnation Pressure}}$ for Nitrogen

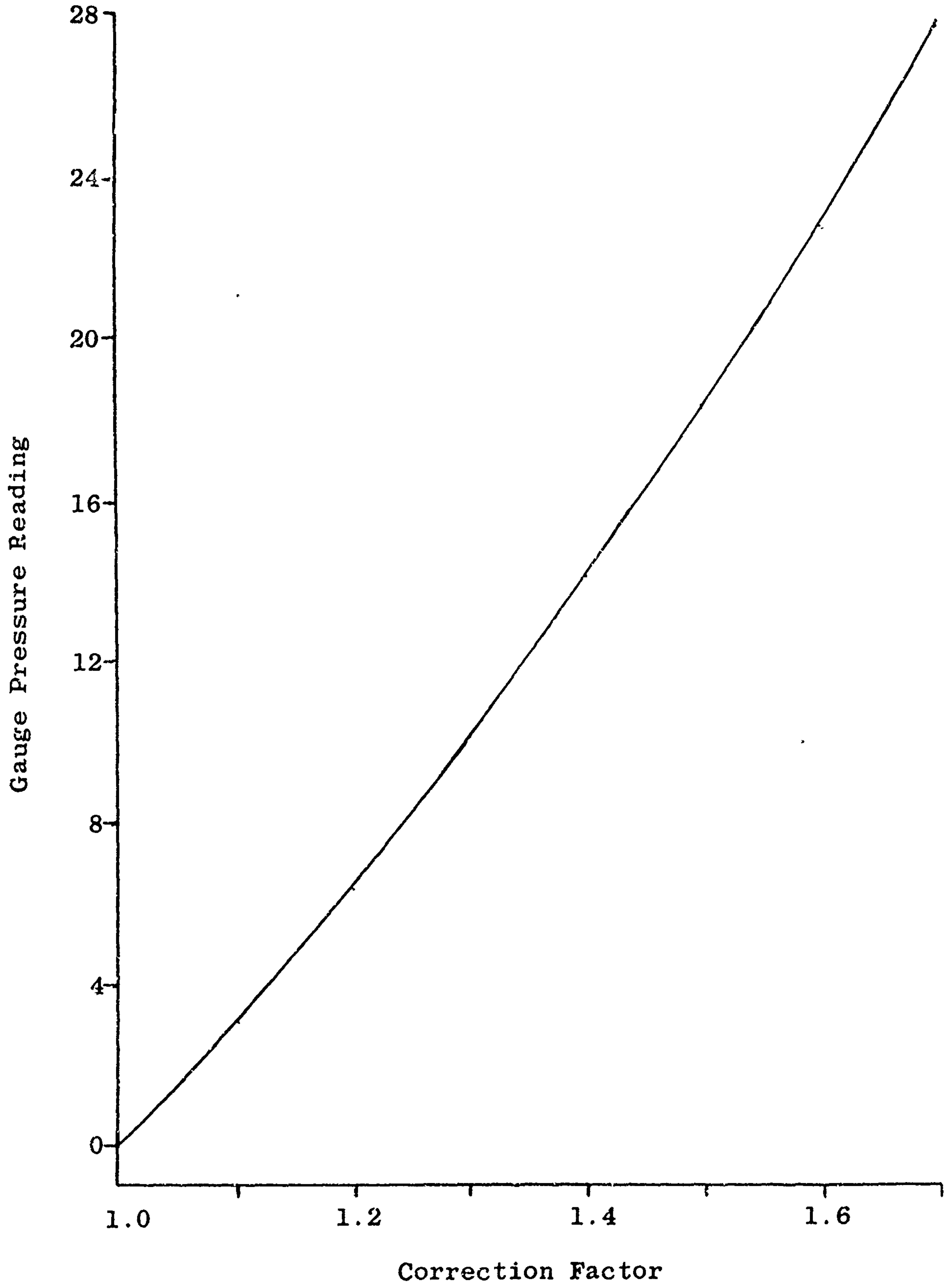

Figure 7. Pressure Correction to Flow Meter Reading

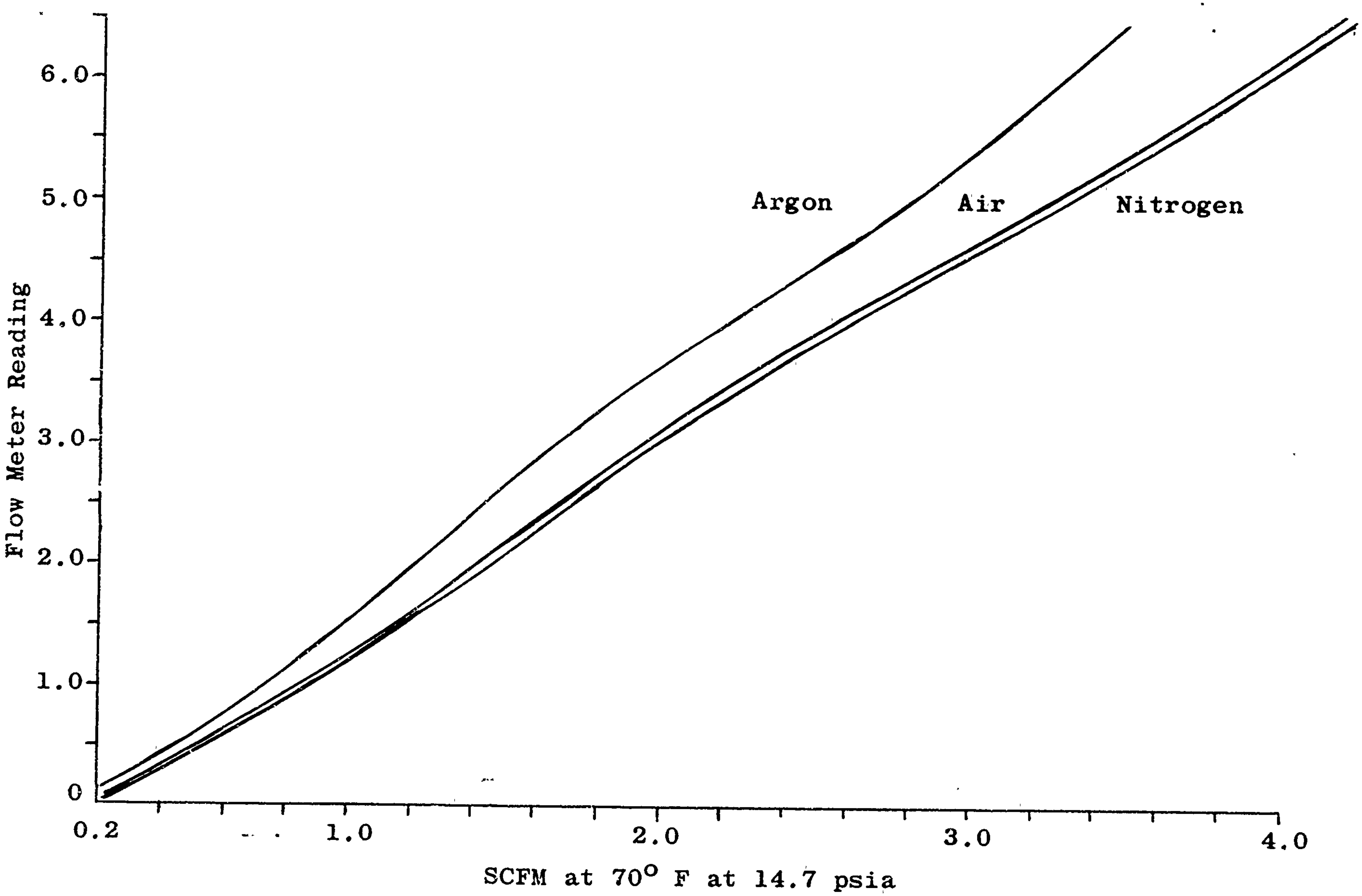

Figure 8. Specific Gravity Correction to Flow Meter Reading

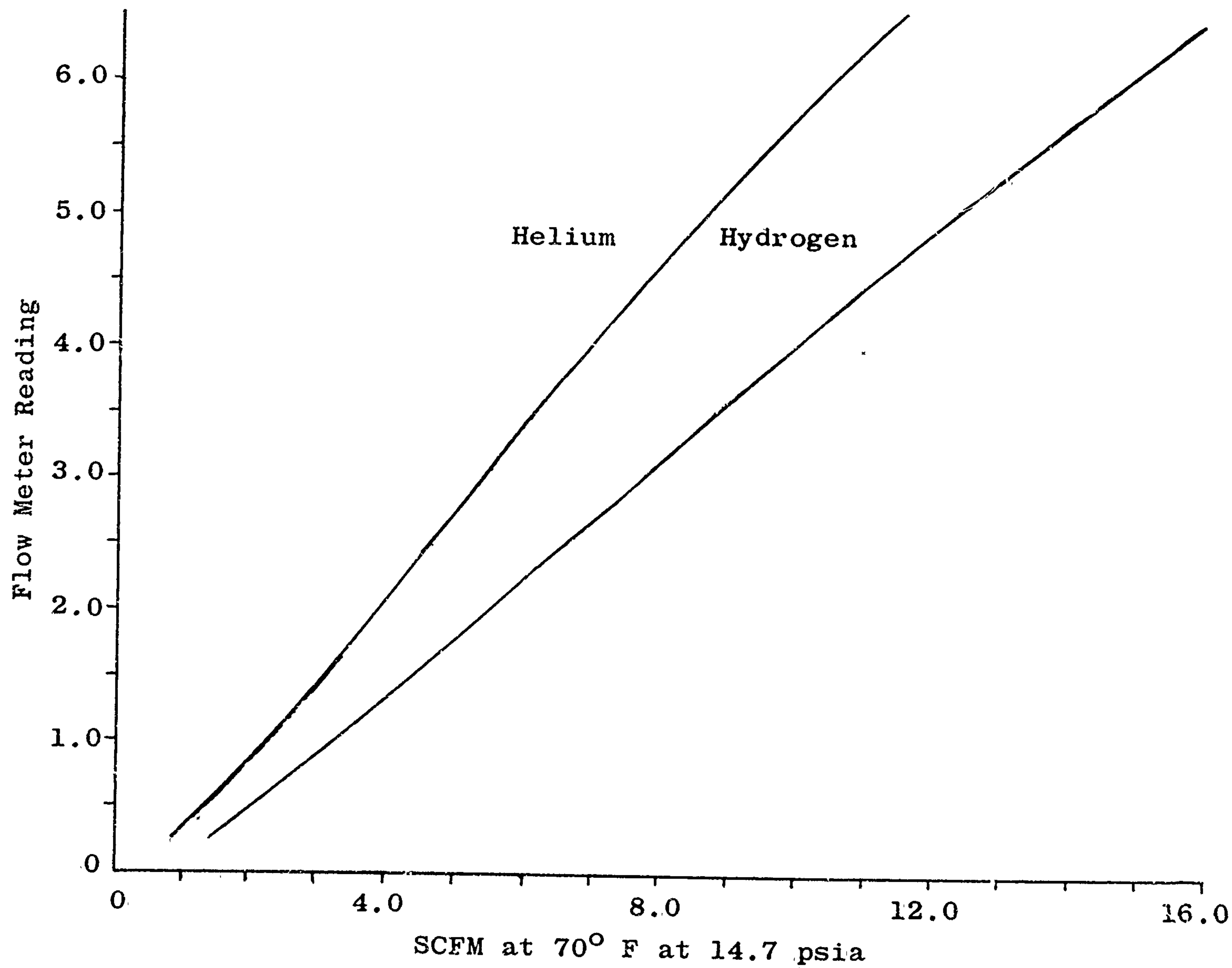

Figure 9. Specific Gravity Correction to Flow Meter Reading

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APPENDIX

STARTING PROCEDURE

Vacuum System

Tank Farm Operation

1. close high pressure valve on compressor line
2. open bleed valve
3. close vacuum valve on compressor line
4. open valve to bottle farm
5. close bleed valve
6. close valve at site
7. close electric switch
8. check oil level (half way)
9. press start button
10. check farm pressure
11. press stop button
12. open electric switch
13. open valve at site

Water System

1. Open main valve
2. check main line pressure (50 psi)
3. close electric switch to start pump
4. check pump pressure (80 psi)
5. open all manifold valves to maximum (90° turn)
6. check drain

STARTING PROCEDURE (continued)

Gas System

1. release bleed valve
2. open bottle valve (250[illegible] psi)
3. adjust bleed valve (50 psi)
4. open valve at console (1.5 @ 12 psi)

Electrical System

1. check shunting in transformer
2. plug in console (120 v)
3. press master switch "on"
4. close wall switch
5. close floor switch
6. press arc power "on"
7. adjust power control

   read "40" for argon

   read "80" for nitrogen
8. depress and hold "auto start" button
9. release "auto" 4-6 seconds after light occurs
10. arc in operation
11. for nitrogen <u>only</u>: immediately reduce power control to read "60"